INCREASE OF THE PROPELLER EFFICIENCY BY VARIABLE RPM

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Abstract

Performance of the in-flight adjustable propeller is computed for the cases with constant RPM (i.e. standard constant-speed propeller) and variable RPM. Propeller 5686-R6 was used due to the public availability of the measured characteristics. Identical engine power is used for both cases. The comparison of results shows that leads to the improvement of propeller efficiency in the magnitute of several procents without change of the blade geometry. Results can be generalized due to the qualitative similarity of the propeller characteristics with the other propellers. Intended usage of this method is for the increase of the propulsion system efficiency for the electric powered UAVs.

1. SYMBOLS AND ABBREVIATIONS

c_P	Propeller power coefficient, $P/\rho n^3 D^5$.
c_T	Propeller thrust coefficient, $T/\rho n^2 D^4$.
D	Propeller diameter [m].
n	Propeller revolution per second [s^{-1}].
P	Power consumed by propeller [W].
T	Propeller thrust [N].
V	Flight Velocity [$m.s^{-1}$]
η	Propeller efficiency.
λ	Propeller advance ratio, $\lambda = V/nD$.
ρ	Air density [$kg.m^{-3}$].

2. INTRODUCTION

Propeller Diameter and RPM is usually considered as input parameter for propeller aerodynamic design (both in newer and older works [1-8]). However, both parameters have considerable influence on efficiency (see FIG. 1). Thus the application of the most advanced design method will lead to quite bad results if input parameters are not suitable for given application.

Development of electric powerplants enables their usage for aircraft propulsion [9]. Electric engines can reach high efficiency and ist nominal power in wide range of engine RPM. This means that variable propeller RPM can be used for electric powered aircraft (both unmanned and manned). Influence of variable rotor RPM on rotorcraft performance is described in [10]. Possibility of increasing propeller performance by adequate control of propeller RPM is presented in this paper.

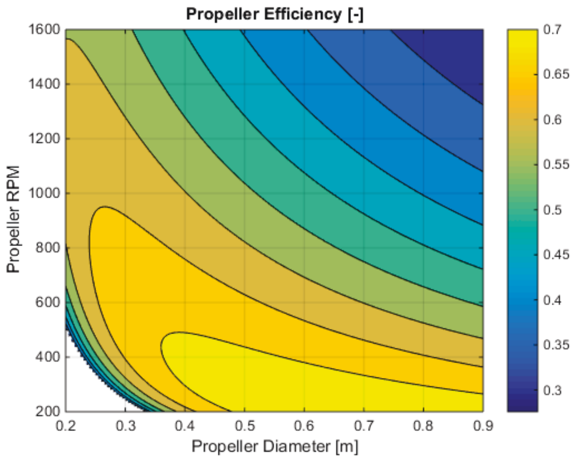

FIG. 1. Dependence of propeller efficiency in the design point on the diameter and RPM (this propeller is for low-speed small UAV and works at very small Reynolds numbers, which causes low lift to drag ratio and thus low efficiency). Goldstein method was used for propeller aerodynamic design [11].

3. METHODS

Optimization of the propeller RPM is based on the experimental data from [12]. This data set is chosed due to its avalaibility in public domain. It contains not only graphs of dimensionless propeller characteristics, but also tables with its values. Characteristics of modern propellers are usually accessible not public or the information is confidental.

The propeller 5868-R6 is used for the further analysis. It is three-blade propeller with 3 meter diameter and RAF 6 airfoils. Characteristics of different propellers shows qualitative similarity so the results of the analysis can be generalized. Influence of variable RPM on performance for other propellers will be similar and can be analyzed if propeller characteristics are known. Characteristics of the Propeller 5868-R6 according to [12] are presented in FIG. 2-4. MATLAB function interp1 was used for the curve interpolation with splines.

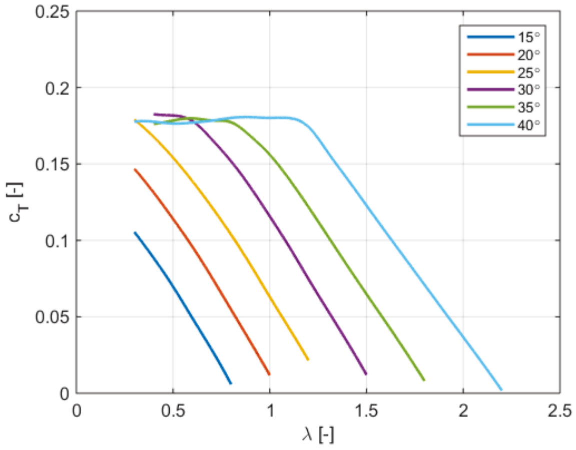

FIG. 2. Propeller 5868-R6 characteristics – dependence of the thrust coefficient c_T on the advance ratio λ from [12].

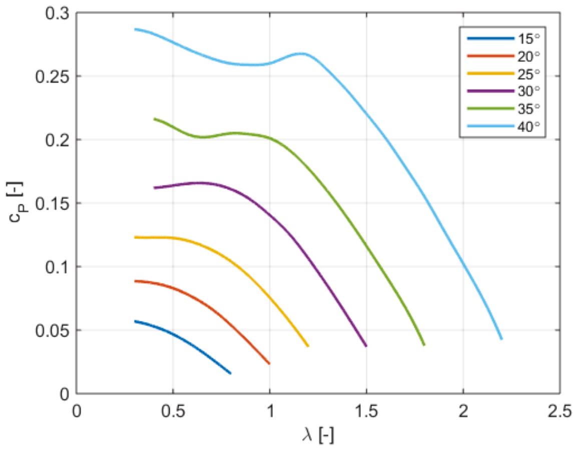

FIG. 3. Propeller 5868-R6 characteristics – dependence of the power coefficient c_P on the advance ratio λ from [12].

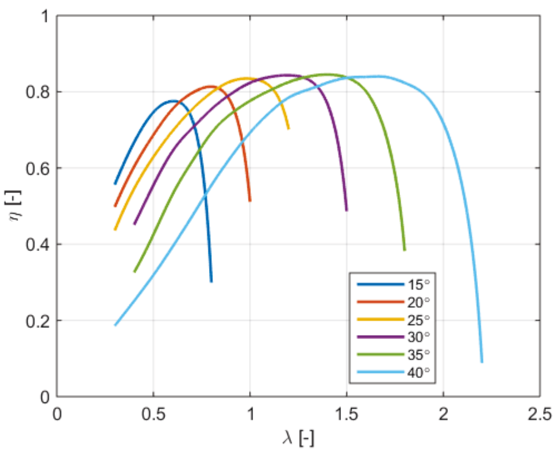

FIG. 4. Propeller 5868-R6 characteristics – dependence of the propeller efficiency η on the advance ratio λ from [12].

3.1. Constant-Speed Propeller

Performance of the constant speed propeller was computed for 0 m international standard atmosphere, engine power 150 kW and 1300 RPM. Dependence of efficiency on advance ratio is shown in FIG. 5. This demonstrates considerable decrease of efficiency for higher flight velocity which is tipical for any constant speed propeller. Shift of the point with maximal efficiency towards higher speeds causes worse performance at low speeds.

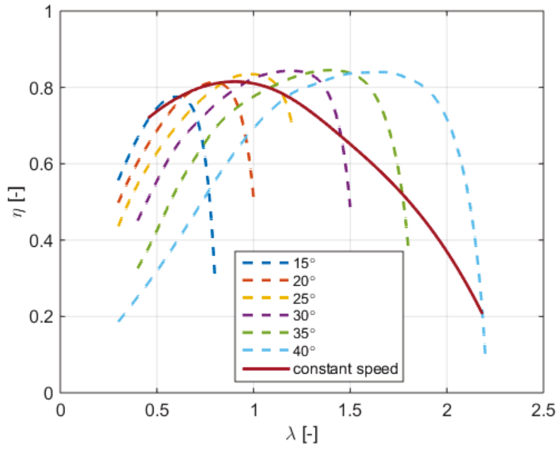

FIG. 5. Dependence of the propeller efficiency η on advance ratio λ for constant-speed propeller (i.e. for constant power coefficient c_P)

3.2. Propeller with variable RPM

Analysis of the propeller with variable RPM assumes usage of the control system which regulates the propeller RPM so that maximum possible propeller efficiency is reached for any flight velocity and engine power. Computations are performed or engine power 150 kW and 0 m international standard atmosphere (i.e. same as for constant-speed propeller) so that results can be compared.

MATLAB software was used for the computations. Analysis consists of following steps:

1. Computation of propeller RPM and flight velocity for each blade setting and given engine power (see FIG. 6). Computation is performed for any point on the propeller characteristics (i.e. point defined by blade angle setting, c_T, c_P, λ and η).

(1) $$n = \sqrt[3]{\frac{P}{c_P \rho D^5}}$$

(2) $$V = \lambda n D$$

2. Dependence of propeller efficiency on flight velocity is set for all blade angle settings (see FIG. 7).

3. Results from steps 1 and 2 are used for the computation of the dependence of efficiency on

propeller RPM for each speed of flight (example is presented in FIG. 8).

4. Optimal propeller RPM for each flight velocity is computed as the maximum of the curve from the step 3.

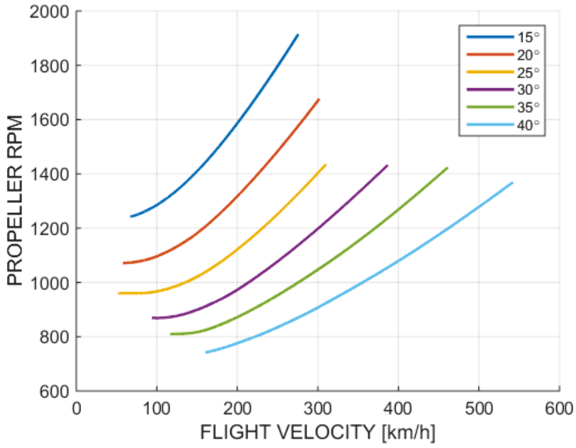

FIG. 6. Dependence of the propeller 5686-R6 revolution per minute on the flight velocity for the constant engine power 150 kW for various blade set angles.

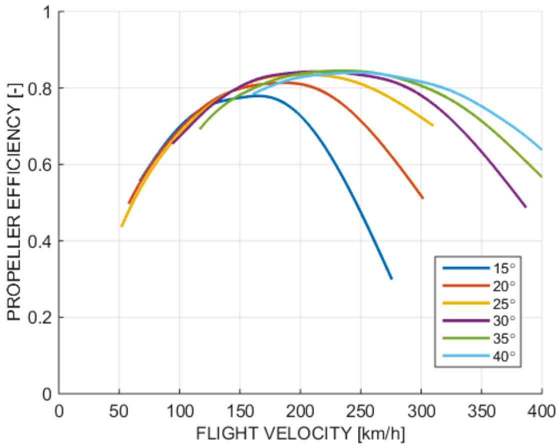

FIG. 7. Dependence of the propeller 5686-R6 efficiency η on the flight velocity for the constant engine power 150 kW for various blade set angles.

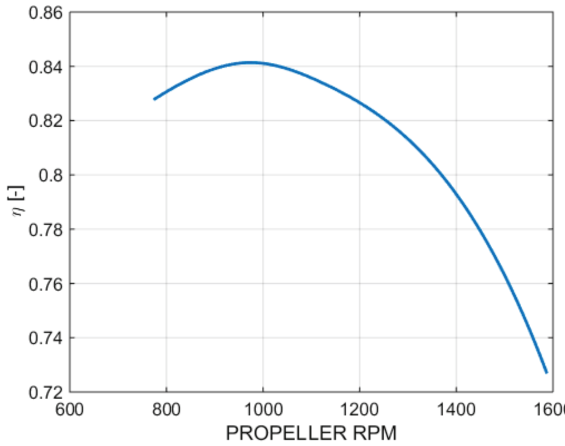

FIG. 8. Dependence of the propeller efficiency η on the RPM for given flight velocity (in this case 200 km/h).

4. RESULTS

Efficiency of constant-speed and variable RPM propellers are compared in FIG. 9. Change in Propeller RPM leads to higher efficiency and partially eliminates efficiency decrease for higher flight speeds. FIG. 10 shows that maximum possible efficiency for given flight velocity, engine power and propeller blade geometry can be reached by the variation of RPM.

Dependence of the optimal propeller RPM on the flight velocity is shown in FIG. 11. Maximization of the propeller efficiency leads to the RPM increase in low speed which must be taken into the account during the design layout of the whole propulsion system so that high Mach numbers at blade tip and corresponding noise problems are prevented.

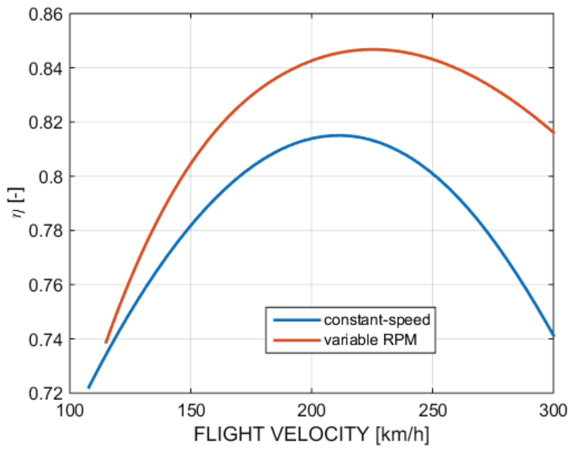

FIG. 9. Comparison of the propeller efficiency η between constant-speed and variable-speed propellers.

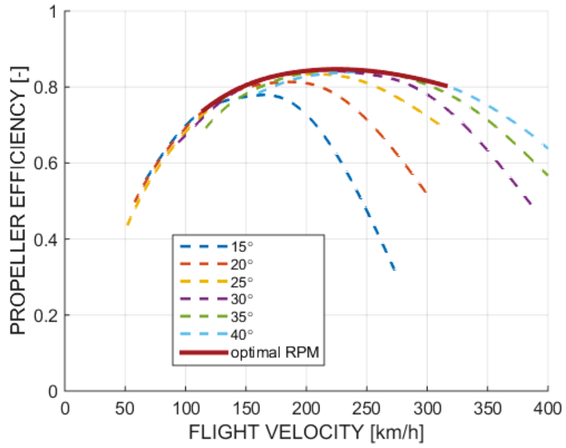

FIG. 10. Maximal possible efficiency in wide range of flight velocity can be reached by change of propeller RPM.

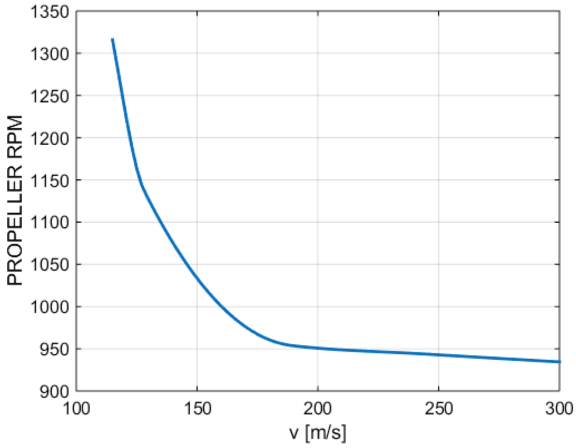

FIG. 11. Dependence of optimal propeller RPM on flight velocity for constant engine power.

5. CONLUSION

Performance of the in-flight adjustable propeller is computed for the cases with constant RPM (i.e. standard constant-speed propeller) and variable RPM. Propeller 5686-R6 was used due to the public availability of the measured characteristics. Identical engine power is used for both cases. The comparison of results shows that leads to the improvement of propeller efficiency in the magnitute of several procents without change of the blade geometry. Results can be generalized due to the qualitative similarity of the propeller characteristics with the other propellers.

Controlled variation of the propeller RPM depending on actual engine power and flight velocity has potential to considerable increase in propeller performance. In the future, method will be tested at electric powered UAVs. Implementation for the optimisation of the efficiency of the turboprop propulsion system is also considered as a possible future application.

6. ACKNOWLEDGEMENTS

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